NESS 69

An Evaluation of May 1971 Satellite-Derived Sea Surface Temperatures for the Southern Hemisphere

P. KRISHNA RAO

WASHINGTON, D.C.
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AN EVALUATION OF MAY 1971 SATELLITE-DERIVED SEA SURFACE TEMPERATURES FOR THE SOUTHERN HEMISPHERE

P. Krishna Rao
Environmental Sciences Group
National Environmental Satellite Service
NOAA, Hillcrest Heights, Md.

ABSTRACT. An objective analysis program was used to derive sea surface temperature distribution over the Southern Hemisphere for May 1971. These observations were obtained from the NOAA 1 satellite. The derived temperatures were subjected to an analysis program and daily sea surface temperature charts were generated.

Examples of a daily and a monthly mean sea surface temperature chart are shown. Satellite-derived brightness values and sea surface temperature changes were used to construct time-longitude sections over the eastern part of the South Pacific for May 1971 to study the variations in these two parameters. The sea surface temperatures derived from NOAA 1 data showed good agreement with conventional ship data of the National Marine Fisheries Service.

1. INTRODUCTION

Sea surface temperatures in selected regions of the oceans in both the Northern and Southern Hemispheres (Smith et al. 1970, Rao et al. 1972, Shenk and Salomonson 1972) have been derived from satellite infrared radiation (IR) measurements. In spite of system noise in both the high-resolution IR (HRIR) data from NIMBUS satellites and the medium-resolution IR (MRIR) measurements from the Improved TIROS Operational Satellite (ITOS) and NOAA 1 satellite, sea surface temperatures could be derived with an absolute accuracy of 2°C or better. For most of the studies the information used was obtained in one infrared window channel, while for some other studies multichannel information was used (Smith and Rao 1972, Shenk and Salomonson 1972) to minimize the influence of clouds on the surface temperature determination. All the above studies cited showed the feasibility of obtaining sea surface temperatures under relatively cloud-free conditions and the procedures used for these studies generally were objective.

Operational environmental satellites now in orbit carry HRIR instruments and Very High Resolution Radiometers (VHRR) primarily designed for mapping the cloud cover by day and by night. The information obtained from these radiometers has shown that it is feasible to detect and monitor oceanic

features such as thermal fronts, current boundaries, meanders and eddies, at least under relatively cloud-free conditions. When satellite radiation data over long periods of time become available, it will be possible to study the temporal and spatial variations of sea surface temperatures over many regions. This study shows an example of mean monthly sea surface temperature distribution in the Southern Hemisphere derived from satellite radiation data for May 1971. Temperature changes over the eastern part of the South Pacific Ocean for this period are also discussed and comparisons are made with conventional data.

2. DATA SOURCE

Data used in this study were obtained from the NOAA 1 satellite launched in December 1970. NOAA satellites are operational environmental satellites and were formerly known as the Improved TIROS Operational Satellites (ITOS); a full description of the system is given in the ITOS project report (Goddard Space Flight Center 1970). In brief, the satellite is a three-axis stabilized, Earth-oriented spacecraft designed to provide complete daily day and night coverage of the globe. It is a polar-orbiting satellite with an altitude of approximately 1500 km and carries two dual channel radiometers. One of the channels measures the radiation emitted from Earth and its atmosphere in the 10.5-12.5 μm region. The instantaneous field-of-view of the instrument results in a viewed spot at the earth's surface 8 km in diameter at the nadir. The global measurements are stored in a tape recorder on the satellite and are transmitted to the ground for computer processing.

The infrared (IR) data obtained from the satellite are corrected for absorption by water vapor in this spectral interval. The corrections vary with the viewing angle of observation, the atmospheric water vapor content, and the cloud conditions. Data presented in this paper have been corrected for atmospheric attenuation using a method developed by Smith et al. (1970).

Sea surface temperature estimates were derived from the NOAA 1 IR measurements by using the histogram method developed by Smith et al. (1970). In this method a large number of observations over an area larger than that covered by most clouds is examined; by using the empirical rule mentioned in the above reference, sea surface temperature can be derived over most areas that are relatively cloud free. The method is objective and can be implemented by means of a digital computer. The derived sea surface temperatures were analyzed by the objective method developed by Holl et al. (1971) to produce the complete sea surface temperature analyses over the Southern Hemisphere used in the present study.

3. RESULTS

In studies relating to global or hemispheric distributions of sea surface temperature, a grid developed by the National Meteorological Center (NMC) is used. It consists of 64 x 64 squares over a polar stereographic projection of each hemisphere; the size of each grid square is approximately 2.5° x 2.5° (latitude-longitude) at mid-latitudes. In each grid square, approximately 1,024 satellite IR observations per observation time are used to define a temperature based on the objective technique. Temperatures cannot be

obtained over some areas because of persistent cloud cover; to a certain extent, the effects of extensive cloud cover can be overcome by the objective analysis technique referred to earlier.

The sea surface temperature distribution obtained over the Southern Hemisphere for May 15, 1971 is shown in figure 1; the isotherms are drawn at 2°C intervals. The strong thermal gradient at mid-latitudes is in good agreement with climatology. The warm and cold current regions along the coasts of South America and South Africa, and the warm regions along the Australian Coast are in reasonable agreement with historical observations over these areas. Some centers of low temperatures in the tropical latitudes disagree with the climatological values; this discrepancy can be attributed to cloud contamination of the satellite IR observations. Platt (1972) compared the satellite-derived temperatures over a 3-day period with the sea surface temperatures prepared by the Bureau of Meteorology in Australia and found the differences between satellite values and ship temperatures to be between 1° and 2°C. Similar differences have been noted earlier by Smith et al. (1970) and Rao et al. (1972).

A mean monthly Southern Hemisphere sea surface temperature chart for May 1971 was produced using the daily charts. The daily values at each grid point were averaged to obtain the mean monthly value. Figure 2 shows the mean monthly sea surface temperature obtained from NOAA 1 scanning radiometer infrared (SRIR) data; this is the first such map known to have been obtained by using satellite IR data exclusively. Even in this average monthly chart, the warm and cold regions along the coasts of South America, Africa, and Australia are noticeable. It is possible that the influence of clouds on the satellite observations might not have been removed completely, so some of the low-temperature areas in the tropics may be attributed to cloudiness. Mean monthly sea surface temperatures from this map will be compared with independent data and discussed later.

Time-longitude sections prepared from the daily NOAA 1 sea surface temperature charts for 5°, 10°, 15°, and 20°S are shown in figures 3-6. The daily charts show interesting temperature departures over the eastern South Pacific; the time-longitude sections portray some of these departures. Also shown in figures 3-6 are digitized brightness values for the corresponding period obtained from NOAA 1 satellite vidicon information. These relative brightness values are given on a scale of 1 to 10. The contours are drawn at intervals of 1, and brightness values greater than 2 are shaded to indicate generally cloudy conditions. All the time sections represent a narrow longitude region between 90° and 120°W. Temperature departures rather than actual temperatures are given for each day at these locations. These departures are the daily departures from the mean monthly value at that longitude. Shaded areas indicate a positive temperature departure. In all these figures the emphasis is on the trend in the temperature departures rather than the absolute magnitude of the departure. No attempt will be made to relate the brightness variations to observed temperature departures. The purpose of providing the corresponding brightness is to show that the influence of clouds in the determination of sea surface temperatures has been minimized. Lack of correlation between the two fields is an indication that the derived temperatures represent relatively cloud-free conditions.

Figure 3 shows the brightness distribution and sea surface temperature departures at 5°S. The brightness distribution during the first half of May shows a striped pattern, indicating cloudiness associated with weak tropical disturbances having a period of 2 to 3 days moving through the region. No such brightness pattern appears during the latter half of May. Surface temperature departures for the same period do not exhibit any particular pattern except a general warming trend during the early part of May and again from May 18 to 30.

Brightness distribution and sea surface temperature departures at 10°S, shown in figure 4, differ from those at 5°S. Noticeable cloudiness existed up to May 19 between 90° and 100°W, and scattered cloud conditions prevailed at other locations. The temperature departures show some cooling until May 18, and relative warming during the rest of the period. The region of warming is almost identical to the one shown at 5°S.

Figure 5 shows cloud brightness distribution and sea surface temperature departures at 15°S. Cloudiness seems to have persisted except for the last 5 days of the period. Sea surface temperature departures show two periods of relative warming, one before May 14 and the other after May 20. The period between May 14 and 20 shows relative cooling, the cooling first taking place at 90°W and progressing westward with time. Similar temperature departures are also shown in figure 6, at 20°S, where the relative cooling starts about May 15 at 90°W and seems to progress westward with time. The brightness data for 20°S show only a few cloudy periods compared with 15°S.

Figure 7 shows a comparison of mean monthly sea surface temperatures obtained from satellite IR data with those published by the National Marine Fisheries Service (1971) (NMFS). Between 100°W and 180°W there is good agreement between both sets of data, but between 100°W and the coast of South America there is a wide discrepancy. Because the NMFS analysis there is based on very sparse ship data, it probably does not correspond to the actual distribution. The satellite-derived sea surface temperature distribution shows a cool tongue of water extending from 30° to 10°S along the South American Coast. Since there is good agreement where ship data are plentiful, perhaps more reliance can be placed on the satellite temperatures where ship data are missing as in this case.

Another way to validate the satellite-derived sea surface temperatures is to construct latitudinal profiles and compare them with independent sets of data. One such comparison is shown in figure 8. Two profiles were constructed: one along 160°W and the other along 130°W. All the data are for the month of May 1971 except Wyrtki's (1964), which is climatology for May. The conventional data are profiles derived from the May 1971 sea surface temperature chart produced by the National Marine Fisheries Service. The conventional data coverage extends from the Equator to 30°S, but Wyrtki's data extend to 40°S. The overall agreement is good at both longitudes, although there is 2° to 3°C difference between Wyrtki's values and the satellite data at 30° and 35°S. In the equatorial region the satellite profiles show lower temperatures than the other data. The gradients shown between 25° and 40°S are in good agreement. At least, by making comparisons of this kind whenever independent sets of data are available, the use of satellite observations can

be extended to data-sparse areas where conventional information is almost nonexistent.

4. COMMENTS ON THE VALIDATION OF SATELLITE-DERIVED SEA SURFACE TEMPERATURES

During the past few years a number of attempts have been made to derive sea surface temperatures from satellite window (8-12 μm) radiation data. Many of the studies (Smith et al. 1970, Rao et al. 1972) have shown that the root mean square (RMS) differences between the sea surface temperatures obtained from ship reports and those from satellites varied between 1.5° and 2.0°C. Similarly, a number of aircraft studies (Pickett 1966, Shaw and Irbe 1972) performed in the United States and Canada to determine the sea surface temperatures by remote sensing show results similar to the satellite studies. Table 1 summarizes some of the findings. The range of RMS differences

Table 1.--Comparison of root mean square (RMS) differences in in the determination of sea surface temperatures from various satellite and aircraft radiation data.

		RMS Difference °C
Nimbus II HRIR	1966	1.7
ITOS SRIR	1970	1.8
NOAA 1 (S. Hemisphere) (with Australian data)	1971	1.6
$\overline{\Delta T} = \overline{(T_{ship} - T_{sat})} = 0.5°C$		
NOAA 2 (N. Hemisphere)	1973	1.6
$\overline{\Delta T} = \overline{T_{ship} - T_{sat})} = 0.7°C$		
Canadian studies aircraft vs. ships		1.7
U.S. Naval Oceanographic Office (Pickett)		
$\overline{\Delta T} = \overline{(T_{ship} - T_{ART})} = 1°C$ (range 0.3°C - 1.8°C)		

between the ship measurements and the remotely sensed values is about 1.5° to 2.0°C, the ship reports being higher by 0.5° to 1.0°C. Some of this variability could be due to the different techniques used in measuring temperatures from ships and part could be attributed to the uncertainties in the

atmospheric attenuation corrections used in this and the other studies (Rao et al. 1972, Maul and Sidran 1973). The attenuation corrections based on the present knowledge about atmospheric water vapor transmission and the effects of other particulates have not been considered. James and Fox (1972) have analyzed large amounts of extensive sea surface temperature data from ship reports and showed large variabilities in the data. They emphasized the need for adopting a standard technique to measure and define sea surface temperature. Until a well-defined standard is established, satellite-derived sea surface temperatures cannot be compared strictly with all the various types of ship reports (bucket temperatures, intake temperatures, etc.).

5. SUMMARY AND CONCLUDING REMARKS

It has been shown that one can objectively derive sea surface temperatures from satellite IR information over large areas. The feasibility of generating a mean monthly sea surface temperature chart using only the satellite information has also been demonstrated.

A comparison between sea surface temperature analyses obtained from satellite IR data and an analysis based on conventional ship data showed good agreement. From recent comparisons of ship, aircraft, and satellite data, one can conclude that with the present state of the art it is possible to objectively derive sea surface temperatures from satellite IR data with an absolute accuracy of 1° to 2°C.

ACKNOWLEDGMENTS

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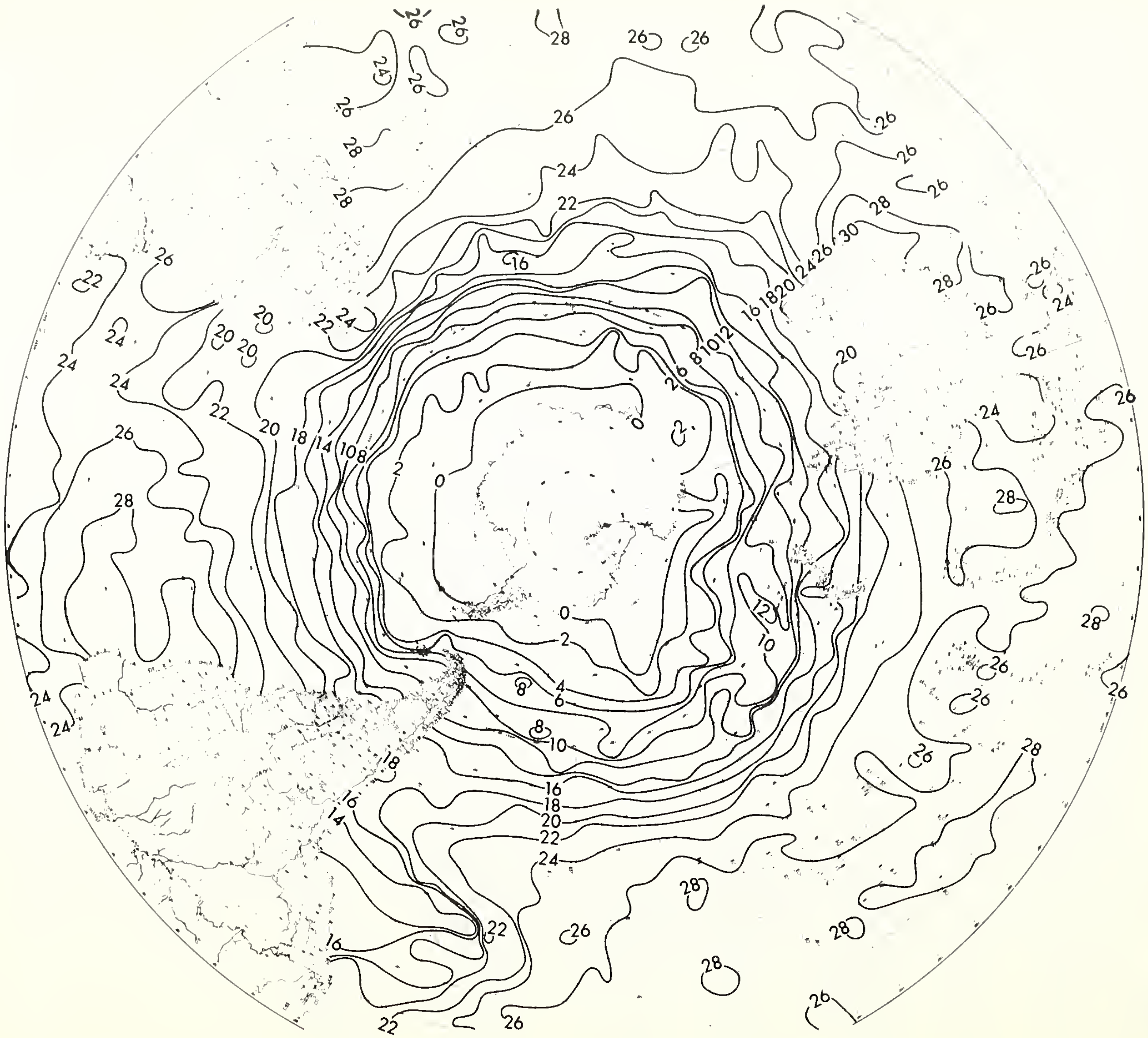

Figure 1.--Southern Hemisphere sea surface temperature analysis derived from NOAA 1 scanning radiometer data for May 15, 1971. No isotherms are drawn for values less than 0°C.

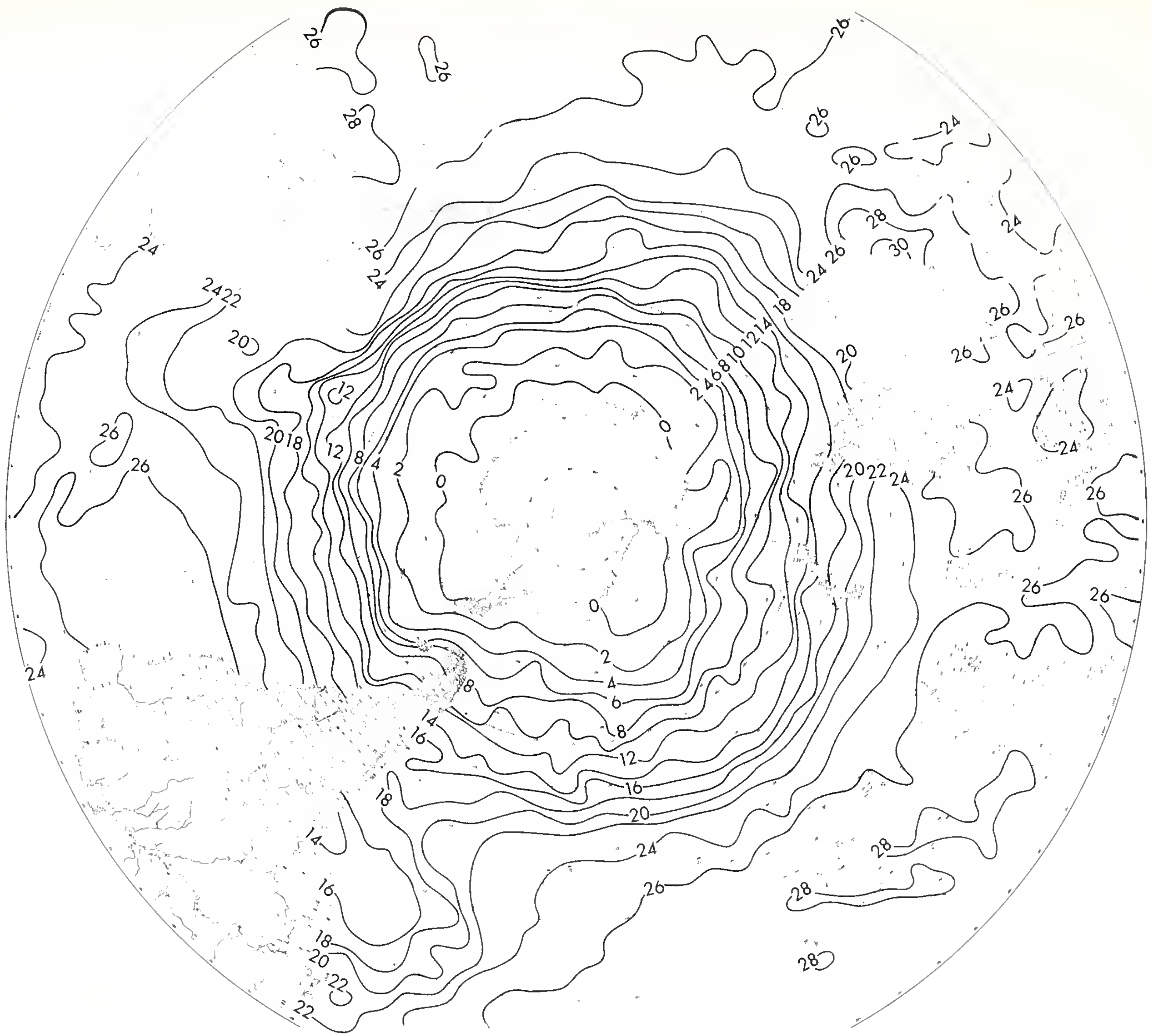

Figure 2.--Southern Hemisphere mean monthly sea surface temperature analysis for May 1971, derived from NOAA 1 scanning radiometer data. No isotherms are drawn for values less than 0°C.

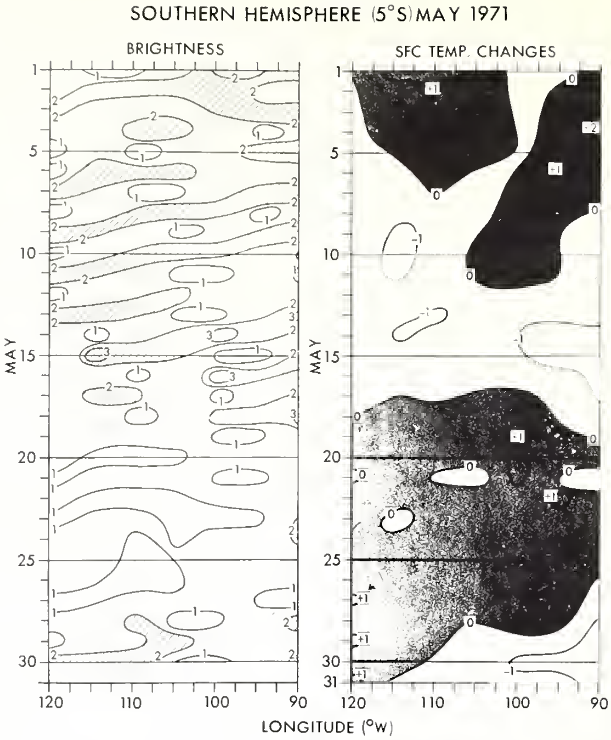

Figure 3.--Time-longitude section showing the brightness and temperature departures at 5°S derived from NOAA 1 satellite data for May 1971. Brightness units vary from 0 to 9; temperature departures are in degrees C.

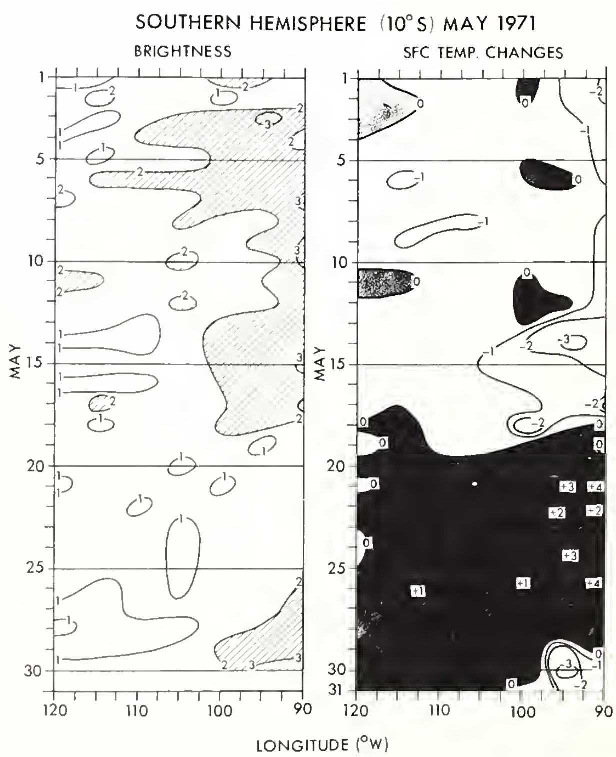

Figure 4.--Same as in figure 3 for 10°S.

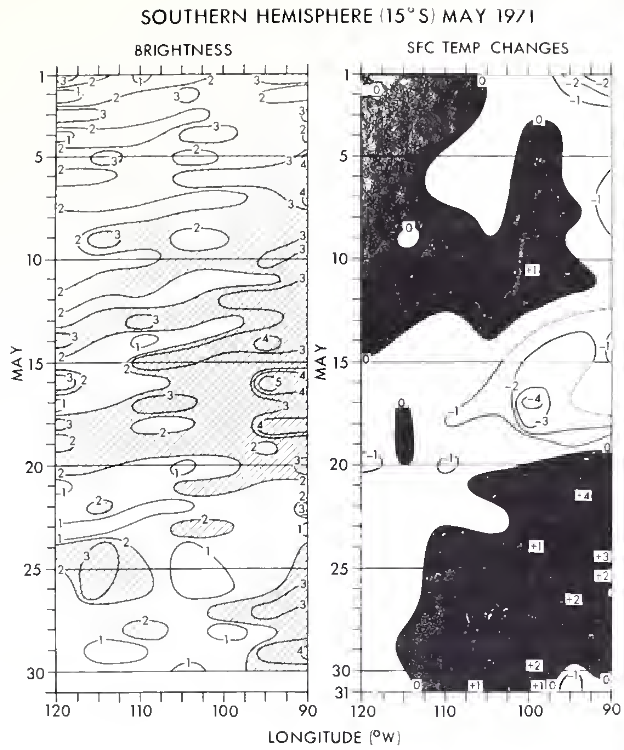

Figure 5.--Same as in figure 3 for 15°S.

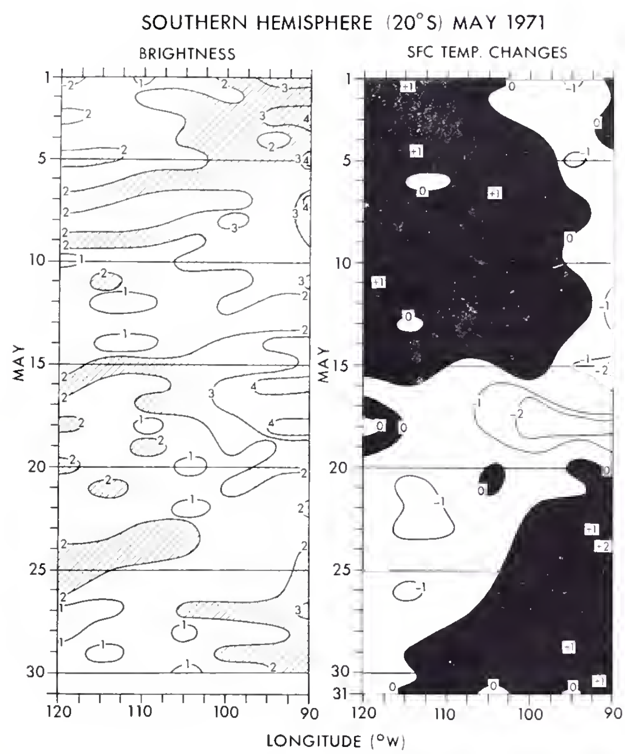

Figure 6.--Same as in figure 3 for 20°S.

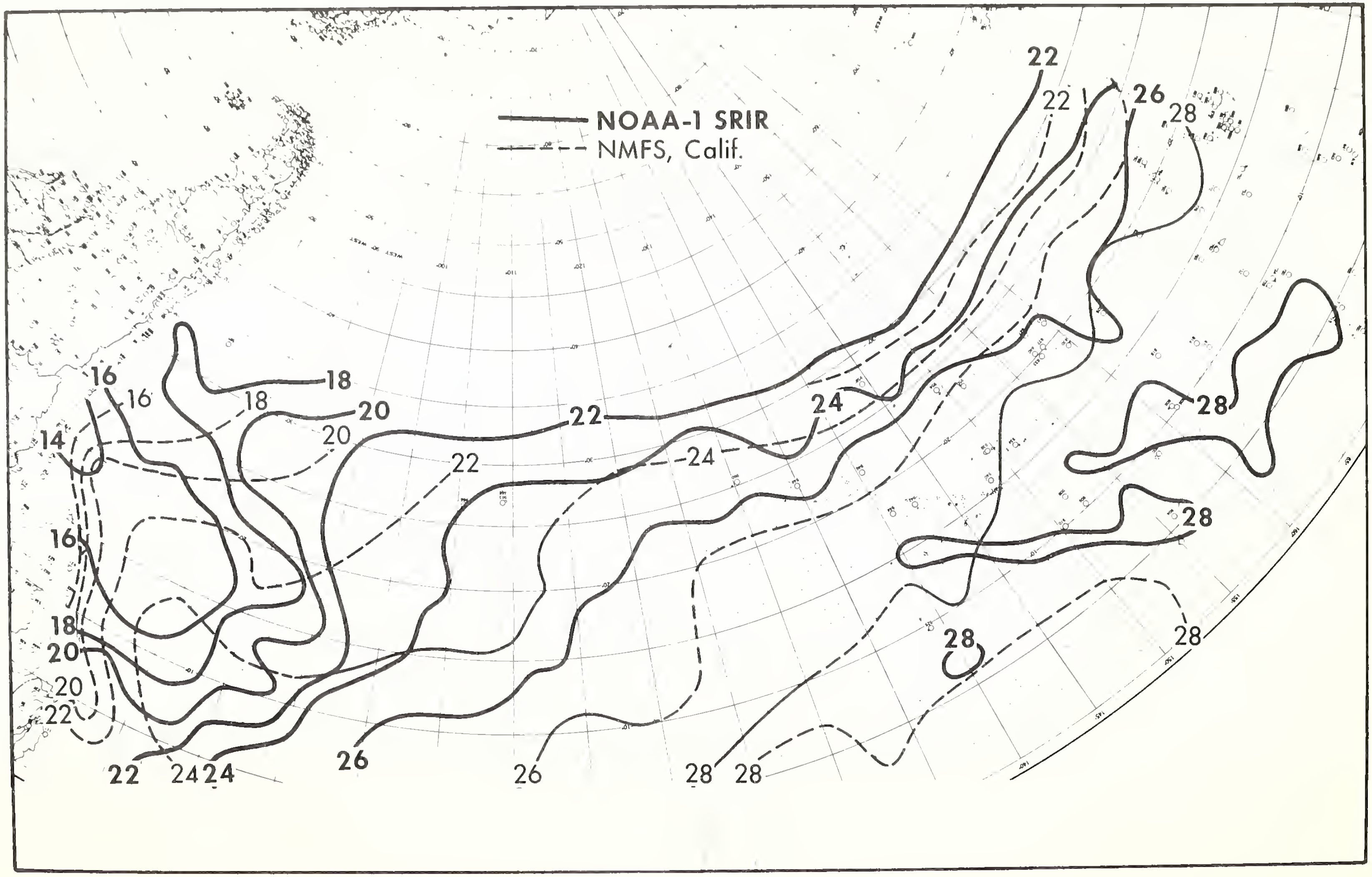

Figure 7.--Comparison of mean monthly sea surface temperatures over the Southern Pacific Ocean for May 1971 derived from NOAA 1 scanning radiometer data and analysis of ship data by the National Marine Fisheries Service. Thin broken lines indicate sparse data.

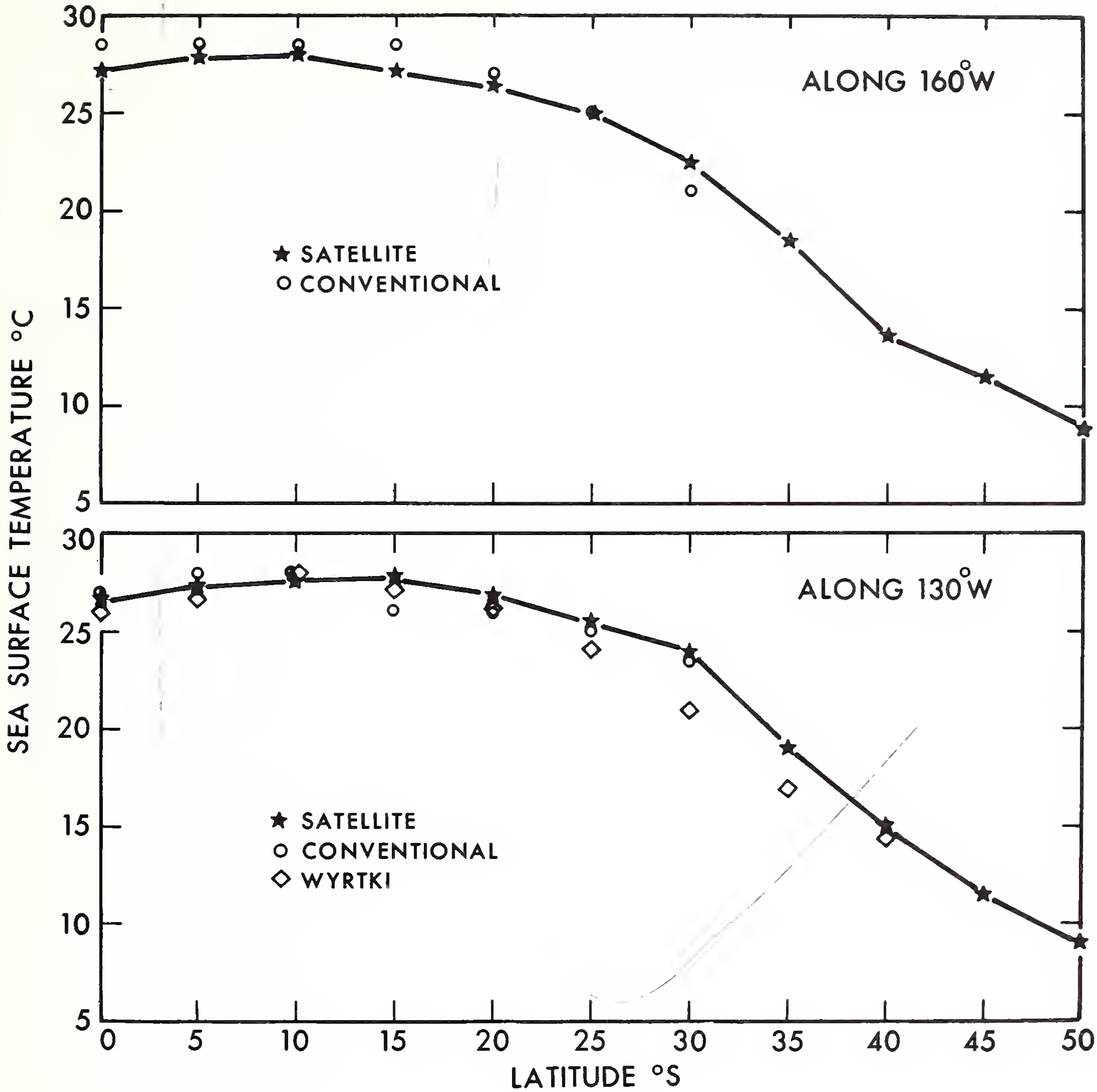

Figure 8.--Comparison of mean monthly latitudinal sea surface temperature profiles at 130° W and 160° W over the Southern Hemisphere for May 1971. Satellite observations were obtained from NOAA 1 scanning radiometer data and conventional data from the National Marine Fisheries Service.

(Continued from inside front cover)

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